# TOUGHNESS INVESTIGATION ON FERROUS-NONFERROUS WELD METAL JOINT (GALVANIZED IRON-ALUMINIUM ALLOY)

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## ABSTRACT

Dissimilar metal welding is still a new field that need more scientific research in order to apply in industry. This thesis deals in study and finding the toughness of welded of galvanized iron and aluminium alloy. The objective of this study are to investigate of toughness of dissimilar metal welding between galvanized iron (GI) and aluminium alloy (AA1100) and also to study optimize parameters of dissimilar metal welding by using aluminium filler AA5356 using Taguchi method. Nine experiments need to be conducted, and then toughness, hardness and microstructure test were conducted. The parameters used are current (110 A, 115 A, 120 A), voltage (17V, 18 V, 19 V), speed (3 mm/s, 4 mm/s, 5 mm/s) and angle (0°, 15°, 35°). From the result, it can be seen that current is the most influential parameter followed by speed and voltage in toughness and also based on Taguchi analysis, the optimize parameter is Current (115 A), Voltage (17 V) and Speed (5 mm/s), this optimize parameter were verified through confirmation experiment. The Regression analysis shows the equation of toughness strength. The microstructure observation shows common defects happen on dissimilar metal welding.

## ABSTRAK

Kimpalan berlainan logam masih lagi bidang baru yang perlu diteroka dan perlu dilakukan penyelidikan yang lebih mendalam dimana teknologi amat penting dalam era yang mencabar. Dalam tesis ini, pencarian dan pembelajaran dilakukan berkaitan mengenai kelasakan kimpalan di antara besi bergalvani (GI) dan aluminium aloi (AA1100) menggunakan aluminium wayar AA5356. Ini juga melibatkan penyelidikan parameter yang telah dioptimumkan untuk proses kimpalan menggunakan kaedah Taguchi. Sembilan eksperimen perlukan dilakukan sebelum diteruskan ke ujian kelasakan, kekerasan dan mikrostruktur. Parameter yang digunakan didalam eksperimen ini adalah: arus (110 A, 115 A, 120 A), voltan (17V, 18 V, 19 V), kelajuan (3 mm/s, 4 mm/s, 5 mm/s) dan sudut (0°, 15°, 35°). Berdasarkan keputusan yang diperolehi, dapat dilihat arus adalah parameter yang paling berpengaruh diikuti oleh kelajuan daan akhir sekali voltan dalam kelasakan kimpalan, dan berdasarkan analsis Taguchi, parameter yang dioptimumkan adalah Arus (115 A), Voltan (17 V) dan Kelajuan (5 mm/s). Parameter ini dapat disahkan melalui eksprimen pengesahan yang dilakukan. Analisis regresi juga menghasilkan persamaan untuk kelasakan kimpalan ini. Berdasarkan pemerhatian mikrostruktur pada specimen, dapat dilihat bahawa terdapat kecacatan yang biasa berlaku pada kimpalan berlainan logam.

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| | |
|---|---|
| AA | Aluminium alloy sheet |
| GI | Galvanized iron |
| HAZ | Heat affected zone |
| ASTM | American Society for Testing and Materials |
| MIG | Metal inert gas |
| TIG | Tungsten inert gas |
| DOE | Design of experiment |
| HV | Vickers Hardness Number |
| CTE | Coefficient thermal expansion |
| TEM | Transmission Electron microscopy |
| SEM | Scanning Electron Microscope |
| ANOVA | Analysis of variance |
| DF | Degree of freedom |
| SM | Sum of squares |
| MS | Mean square |
| F | F-function |
| $SS_R$ | Sum of square regression |
| $SS_E$ | Sum of square error |
| $SS_T$ | Sum of square total |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

Hybrid structure between ferrous-nonferrous has a high technical, environmental, economical and energy saving potential. It is because of weight reduction in transportation through light construction. In automotive industry especially, lightweight constructions of vehicle is become particularly important for car manufacturers such as Mitsubishi, Toyota, Volkswagen, Ferrari and others. It is because nowadays peoples and car manufacturers are concern with on global environment.

There are efforts where vehicle is made mainly with aluminium alloys. By doing this, weight of vehicle can reduce up to 50%. However utilization of aluminium on vehicle in a standard conception of steel car body is an attractive compromise between cost and performance. In the next decades, automotive industries are aiming to decrease fuel consumption in order to follow new anti-pollution standards especially in Europe. Car manufacturers are trying to use steel and a light alloy (ferrous or non-ferrous) implies the joining of dissimilar materials such as steel and magnesium or steel and aluminium.

Meanwhile, in oil and gas industry, welding is an essential part of fabrication routes. There is recent growing oil and gas sector to utilize the joining of dissimilar metal, even though worldwide R&D activities related joining metal in automotives are far more visible in professional society, local and international conference. This show how much automotive greatly exceeds those from the oil and gas sector. Usually auto sector are influence by aerospace technology, likewise which oil and gas learn from auto. Around the globe, welding research conducted by scholars appears to be driven by automotives sector. Then, competition will intensifies between oil and gas services companies, companies that have the very best of manufacturing technologies will gain the leading edge. Like the automotives, future profits will come arise from optimized combinations of mechanical design and manufacturing.

## 1.2 PROBLEM STATEMENT

IMC (intermetallic compound) is a structure form in welding seams. It is difficult to control the IMC because of heating temperature changes very quickly, reaction time between the liquid filler metal and solid metal is rather short. A mechanical property of welding seam of dissimilar metal is extremely brittle. The problem also lies between the metal and IMC that spawn in the transition zone. This also can be caused by the lack of fusion together with metal that has low thermal conductivity been fuse by heat with high thermal conductivity metal.

## 1.3 OBJECTIVES

The objectives of this are:

a) To investigate the toughness of dissimilar metal welding between galvanised iron and aluminium alloy.
b) To study the optimization parameter of dissimilar metal welding by filler.

## 1.4 SCOPES OF PROJECT

a) Predict the optimize parameter using Taguchi method approach
b) Relation between welding parameters on microstructure and toughness properties.
c) Weld the galvanized iron (GI) and 1100 aluminium alloy (AA1100).

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 SHEET METAL

Sheet metal is a metal formed into thin and flat pieces of metal. This kind of metal form is often used in metalworking. Usually sheet metal will be cut, rolled, bent and other into variety of different shapes. Foil or leaf is considered the most thin thickness for sheet metal, while metal that thicker than 6 mm are considered as plate. Sheet metal is available in flat pieces or coil strip form in market. Aluminium, steel, copper, tin, nickel and others types of metal can be made into sheet.

Sheet metal has many applications in industries such car making, shipping, aerospace, building structure and many more. Sheet metal of iron and other of metals especially that have high magnetic permeability, also known as laminated steel cores, have many application in electronic industry like transformers and electric machines.

## 2.2 WELDING

Welding is process where the two pieces of metal is joined together by heating to a temperature high enough to cause softening or melting, with or without applying pressure and the use of filler metal. Any filler used for joining metal has either a melting point approximately the same as the base metal that will be joined or a melting that is below these metals but above 426°C.

In the last decades, new application, method, system has been introduced and developed. By simplifying and speeding up industrial processes and making it possible to develop new industries, such as the nuclear power and space industries, it has increased the world the supply's of goods.

## 2.3 DISSIMILAR METAL WELDING SYSTEM

Dissimilar metal welding is refer to the joining of the metals that has difference on chemical composition, physical and mechanical properties, microstructure, melting point, thermal coefficient and thermal conductivity. In the last few years, new processes has been utilized for dissimilar metal welding such as friction stir welding and other different methods involving laser process to join ferrous metal to non ferrous metal alloys (Sierra *et al,* 2008).

Usually all dissimilar metal welding between different metals, ferrous-ferrous or ferrous-non ferrous can lead to the brittleness. Defects that usually found in dissimilar metal welding are crack, porosity, overlap, undercut and slag. It is because intermetallic phases found in fusion zone. There a problem when making welds between dissimilar metals because it relates to the transition zone between the metals and the intermetallic compounds that is formed within transition zone. In the fusion welding, it is important to examine the both metals phase diagram. If any mutual solubility between both metals exists, the dissimilar metal welding can be made successfully but if there is little or no solubility between the two metals to be joined the weld process will not be successful (Sierra *et al,* 2008; Lin *et al*, 2010).

## 2.4 INTERMETALLIC COMPOUND (IMC)

IMC are formed in the joint between aluminium alloy and steel by fusion welding. It has many difficulties since there are large number brittle intermetallic compound. IMC can be control within a few micrometres in solid-state welding in joining dissimilar metal but the joining are restricted by joint's shape and welding equipment's capacity (Kimura *et al,* 2009), (Acarer and Demir, 2008), (Nezhad and Ardakani, 2009) (S.B. Lin *et al*, 2010).

IMC layer growth is more difficult to control because the change of heating temperature is very quick also liquid filler metal and solid steel reaction time is too short. The IMC layer growth happens predominantly in its thickness and microstructure, but coated layer of Zn and Al on steel could improve wetting of filler metal and reduce the IMC's layer growth by doing laser brazing and arc brazing (S.B. Lin *et al*, 2010), (Torkamany *et al*, 2010), (Mathieu *et al*, 2006), (Song W. *et al*, 2006). Addition of Si in filler wire metal can effectively control the growth of Al-Fe IMC layer by replacing Al-Fe binary phases with ternary phases of Al-Fe-Si (Mathieu *et al*, 2006), (Murakami T. *et al*, 2003), (Song W. *et al*, 2006) but Si addition in the filler wire metal got a limited effect in improving the IMC's layer crack resistance against a high brittleness of Al–Fe–Si phase(S.B. Lin *et al*, 2010), (Song J.L *et al*, 2009).

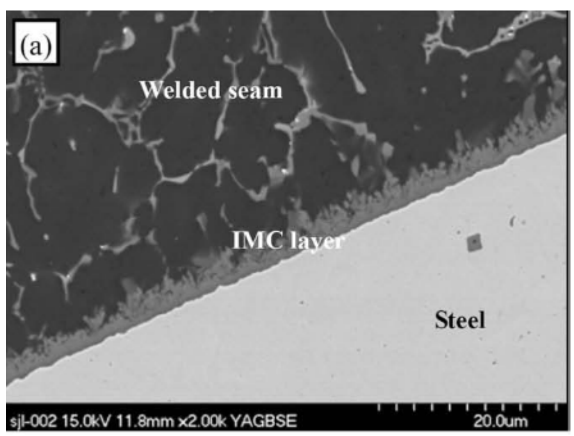


**Figure 2.1:** IMC layer of aluminium-steel joint

Source: Lin *et al*, 2010

The distinction in melting point between both metals that are to be joined also need be studied. The prime study when a welding utilizes heat is involving one metal that will be melted before the other metal when subjected to the same heat source. When metals with different melting points and thermal expansion rates are to be joined together, the welding process with a high heat input will make the weld joint have an advantage.

So the third metals must take a place in joining process which may help to avoid this kind problem. For example, if steel melting point is around 1400-1450°C, while aluminium alloy melting around 600-650°C, so the third metal which is filler metal, it's melting point must be somewhere in the middle of those two base metals. Another solving method may dissimilar metal welding is by using material like steel that coated by zinc or aluminium layer, could improve the filler metal's wetting and inhibit the IMC layer growth (Lin S.B. *et al,* 2010).

## 2.5 METAL INERT GAS WELDING

Metal inert gas welding (MIG) also known as gas metal arc welding is a type welding process that employs continuous consumable solid wire electrode and externally supplied inert shielding gas which causes flow of current to generates the thermal energy in the partially ionized gas (M.A. Wahab et al, 1998). During constantly melting process of electrode wire as it is fed to the weld puddle, a flow of an inert gas or gas mixture will shielded the weld metal from atmosphere by.

It was done to make sure there are no oxidation takes place during welding process. The gas use for the welding process may be hydrogen, helium, carbon dioxide, argon or nitrogen. This kind of welding process does not need a really skillful operator to do the process because of MIG flexibility, versatility and already automated which required less efficiencies and manipulative skill.

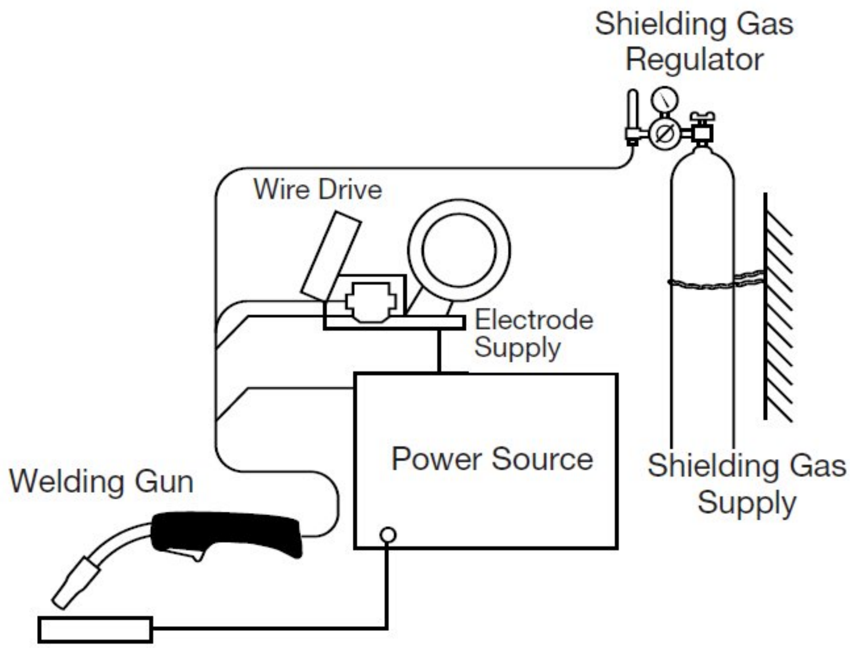


**Figure 2.2:** Basic GMAW system

Source: Lincoln Electric Company, 2006

The advantages of using MIG process is that the melting metal transfer through heat from the consumable wire electrode can be dynamically changed and controlled through a combination of electrode type and form, power source type, shielding gas composition, arc current and voltage, and wire feed rate (Messler, 1993). Among the advantages of MIG processes are (Sacks and Bonhart, McGraw Hill, 2005):

i) The process much faster than other welding process
ii) The elimination of flux and slag reduces the cleaning time considerably
iii) Fewer starts and stops because it use continuous electrode
iv) High quality process and meets the requirements of most codes
v) Good weld appearance
vi) Good penetration, fusion, and smooth weld bead can be produced

vii) Reduced distortion and warpage because the heat being concentration during welding process.

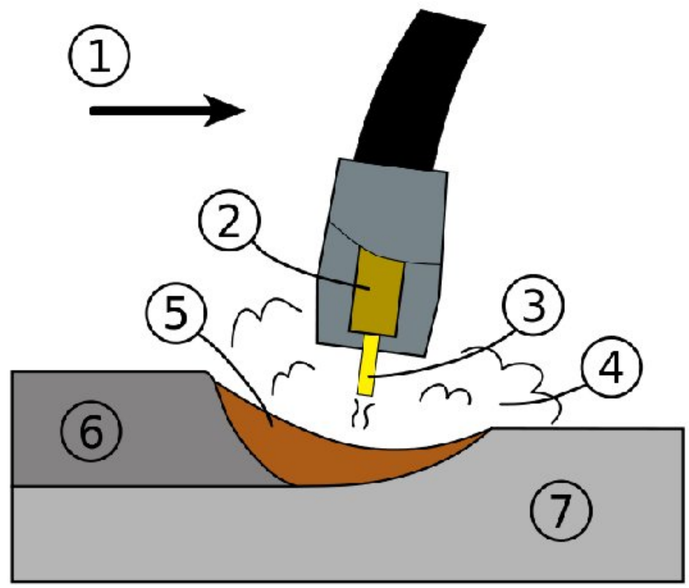


**Figure 2.3:** MIG weld area. (1) Travel direction, (2) Tube of contact, (3) Electrode, (4) Shielding gas, (5) Molten weld metal, (6) Solidified weld metal, (7) Workpiece

Source: Lincoln Electric Company, 1994

## 2.6 WELDING DEFECTS

Welding defects or imperfections often happen during welding process. The defects can greatly affect weld performance and longevity. Many of these defects happen because of: poor process conditions, error cause by operator, wrong technique while doing welding, incorrect consumable and bad weld grooves.

The material to be welded should be inspected thoroughly for surface defects and the presence of contaminating materials. The material should be checked for size, edge, and angle of bevel. The material edges and faces should be free from laminations, blister, nicks and seams. Heavy scale, oxide layer, grease, paint and oil also need to be remove. Make sure the material is a type suitable for welding.

### 2.6.1 POROSITY

Porosity is pockets that occur on the interface of specimen where it do not contains any solid material. The differential with slag inclusion is that pocket does not contain solid material rather gas solely. The gases forming the voids are derived from:

i) Gas released by the cooling weld metal because of its reduced solubility as the temperature drops
ii) Gases forming by chemical reactions in the weld

Excessive porosity in welds has a serious effect on the mechanical properties of the joint. Certain codes permit a specified maximum amount of porosity. Pockets may be found scattered uniformly throughout the entire weld, isolated in small groups or concentrated at the root. Porosity is best preventing by avoiding (Sacks and Bohnart, McGraw Hill, 2005):

i) Overheating and underheating of the weld
ii) Excess moisture in the covered electrode
iii) Contaminated base metal or consumables
iv) Current setting is too high
v) An arc is too long

A metal temperature that is too high increase unnecessarily the amount of gas dissolved in the molten metal. This excess gas is available for release the solution upon cooling. If the welding current and/or arc the length is excessive, the deoxidizing elements of the electrode coating are used up during welding so that there are not enough of them left to combine with the gases in the molten metal during cooling. Underheating does not permit the weld pool to be molten long enough to allow the trapped gases to escape. Reducing all sources of contamination to a minimum will greatly reduce possible gasifiers and help eliminate hydrogen pickup. Shielded gas must be pure, delivered at the proper flow rate and protected from being blown away (Sacks and Bohnart, 2005).

### 2.6.2 CRACK

Cracks are linear rupture of metal under stress. When they are large, they can be seen easily but they are often very narrow separations. Cracks may occur in the weld metal, in the plate next to the weld or in the heat affected zone (HAZ). Cracking results from localized stress that exceeds the ultimate strength of the material. Little deformation is apparent because cracks relieve stress when they occur during or as a result of welding. There are three major classes of cracking: hot cracking, cold cracking and microfissuring (Sacks and Bohnart, McGraw Hill, 2005).

- Hot cracking: occurs at elevated temperature during cooling shortly after the weld has been deposited and has started to solidify. Slight stress causes very small cracks that can be detected only with some of the non-destructive test techniques such as radiographic and liquid penetrant inspection. Most welding cracks are hot cracks.
- Cold cracking: cracking at or near room temperature. These cracks may occur hours or days after cooling. It usually starts in the base metal in the HAZ. May appear as under bead cracks parallel to the weld or as toe cracks at the edge of the weld. Occurring more often in steels than other metals.
- Microfissure: can be either hot or cold cracks. Too small to be seen with the naked eyes and are not detectable at magnifications below 10 power. Usually do not reduce the service life of the fabrication.

### 2.6.3 INCLUSIONS

Generated by extraneous materials such as slag, flux, tungsten or oxide inclusion, usually elongated or globular in shape or may be caused by contamination of the weld metals by foreign bodies. Slag inclusions are generally happen in arc welding, created of the electrode coating materials or fluxes. During the deposition and solidification of the weld metal, the air and the electrode coating materials or the gases produced by arc flames. Some of the products of these reactions are metallic compounds that re only slightly soluble in the molten weld metal. The oxide may be forced down the surface by the stirring action of the arc or it may flow ahead of the arc, causing the metal to be deposited over oxide.

The defects that usually associated with undercut, incomplete penetration and lack of fusion in welds. Inadequate cleaning between multi-pass welds, incorrect and electrode manipulation can leave slag behind after welding process and unused sections along the weld joint. Most inclusions can be prevented by (Sacks and Bohnart, McGraw Hill, 2005):

- Prepare the groove and properly weld before deposited each bead on it
- Avoid leaving any contours that will cause the arc difficult to fully penetrate
- Making sure that all slag has been cleansed from the surface of the previous bead

Slag inclusions not just reduce cross sectional area joint strength but may also works as an initiation point for serious cracking. These defects can only be repaired by grinding out and re-welding the joints.

### 2.6.4 UNDERCUT

Undercut is one of most serious defect in welding process. It is burning away of the base metal at the weld toe or essentially unfilled grooved along the edge of the weld (Baughurst and Voznaks). The defects are often associated with incorrect electrode angles, incorrect weaving technique, excessive current and head torch speed. In the addition to poor welding technique and the type of electrode required, undercutting may be caused by:

- Current adjustment is too high
- Arc length is too long

- Fail to fill up the crater perfectly together with metal weld can permits the arc to range over surface that are not to be covered with weld metal

Undercut at the surface of a joint should be not being permitted since it materially reduces the strength of the joint. To prevent any serious effect upon completed joint, it must be corrected before depositing the next bead. A well rounded chipping tool is used to remove the sharp recess that might otherwise trap slag. If the undercutting is slight and the welder is careful in applying the next bead, it may not be necessary to chip (Sacks and Bohnart, McGraw Hill, 2005).

### 2.6.5 OVERLAP

Overlap also known as incomplete fusion. Weld metal protrusion beyond the weld toe or weld root. This kind of defects is largely the result of incorrect head torch handling, low heat and improper speed of head torch. It is important to direct the arc be to the base metal and the leading edge or the pool. Overlap can be repaired by grinding out the excess weld metal and grinding the surface smoothly to the base metal (Baughurst and Voznaks, Aspec Engineering, 2009). To avoid the defect, give cautious account to the following (Sacks and Bohnart, McGraw Hill, 2005):

- Channel the arc so it can covers all joint area, so the arc can do the fusing, not the pool
- Direct the electrode to the pool front edge
- Reduce the pool size as required by adjusting the head torch speed
- Check current values carefully. Keep a short electrode extension

## 2.7 MASS SPECTROMETER

Spectrometer is one of machine used in determine and identify the chemical compositions of metal or molecule sample. It is an analytical method that measures the charged particle mass-to-charge ratio. In determining sample, a mass spectrometer changes molecules of sample to ions so that they can be moved and manipulated by magnetic fields and electrical field.

The three important components of spectrometer consist:

- The ion source: convert gas phase molecules of sample into ions through, for example, electro spray ionization that let the ions turn into gas phase.
- The mass analyzer: sort and analyse each ions by the mass and charge by electromagnetic fields
- The detector: the ions that have been separated are then measured by the value of quantity indicators. From it, they will provided and the results will be shown on a chart

The spectrometer has practical usage in quantities and qualitative. The machine can also be used in other study in determining physical, chemical or biological properties of any variety of compounds (Chace and Sparkman, 2005).

## 2.8 GALVANIZED STEEL

Galvanized steel or also known as galvanized iron is a special type of iron that can resist corrosion because of coating layer of zinc. Layer of zinc coating will acts as anode on the steel or iron surface (cathode) that protect it through the difference of metals electrochemical potential. The zinc coated on iron is whether hot-dipped or electroplated. Zinc-coated metal is widely used in die casting for making products such as fuel pump, household appliances components (vacuum cleaner, washing machine, photoengraving equipment and others) (Kalpakji an and Schmid, Manufacturing Engineering and Technology, 2006), (Smith and Hashemi, Foundations of Materials Science and Engineering, 2006).

## 2.9 ALUMINIUM

Aluminium is naturally found after the refining of bauxite ore by reducing alumina (aluminium oxide) to aluminium by electricity separation process. Aluminium and its alloy is one of the most used metals in manufacturing industry due to the high strength-to-weight ratio, resistance to corrosion, high thermal and electrical conductivity, nontoxicity, reflectivity and ease of formation and machinbility. The primary products primary products produced and their industrial applications are (Kalpakjian and Schmid, Manufacturing Engineering and Technology, 2006), (Smith and Hashemi, Foundations of Materials Science and Engineering, 2006):

- Sheet: cans, construction material and automotive parts
- Plate: aircraft, and space fuel tanks
- Foil: household aluminium foil, building insulation, and automotive parts
- Rod, bar and wire: electrical transmission lines and the non-rust staples in the bags
- Extrusions: storm windows, bridge structure and automotive parts

## 2.10 TOUGHNESS TEST

There are many name for this test, it is also known as impact toughness test, impact strength test and others. There are two types of methods to test and determined material toughness; Charpy and Izod Impact test, but both of test use same mechanism to fracture the material, which is pendulum testing method. The pendulum will be swing from high point to breaking the middle notched material in one blow. The energy absorbed by the material will be the measure of the toughness test. The toughness of material is greatly affected by the temperature differences, so the test will be repeated for several times with different temperature specimens.

| | |
|---|---|
| 1: length of test bar | 10: draft angle hammer = 30 ° +/- 1 ° |
| 7: anvil gap = 40 +0.2 / 0.0 mm | 11: radius of hammer = 2 + 0.5 / 0.0 mm |